



EFFECTS OF LEGUME COVER CROP AND SUB-SOILING ON SOIL PROPERTIES AND MAIZE (*Zea mays* L) GROWTH IN SEMI ARID AREA OF MACHAKOS DISTRICT, KENYA

[EFECTO DEL CULTIVO DE COBERTURA Y EL SUBSOLADO SOBRE LAS PROPIEDADES DEL SUELO Y CRECIMIENTO DE MAÍZ (*Zea mays* L) EN LA REGIÓN SEMI ÁRIDA DE MACHAKOS, KENIA]

Anne Karuma¹, C.K.K Gachene¹, P.T Gicheru², A. W. Mwang'ombe¹, H.W, Mwangi², D. Clavel³, J. Verhagen⁴, R. Von Kaufmann⁵, J. Francis⁶, W. Ekaya⁷

¹ Faculty of Agriculture, University of Nairobi. P. O. Box 29053- 00625 Kangemi, Nairobi, ² National Agricultural Research Laboratories (KARI). P.O. Box 14733, Nairobi, ³ CIRAD, France, ⁴ Wageningen University, Netherlands, ⁵ FARA, Ghana, ⁶ CTA, Netherlands, ⁷ RUFORUM, Uganda

Email: annekaruma@gmail.com

*Corresponding author

SUMMARY

Low crop yields in the semi arid areas of Kenya have been attributed to, among other factors, low soil fertility, low farm inputs, labour constraints and inappropriate tillage practices that lead to pulverized soils. The aim of this study was to determine the effects of legume cover crops (LCC) on soil properties and maize growth in the semi arid area of Machakos District, Kenya. The study was undertaken in farmers' fields. The field experiments were carried out in a randomized complete block design with four treatments each replicated four times during the 2008/2009 long (LR) and short rain (SR) seasons. The treatments were T1 = maize + dolichos (*Lablab purpureus*) + subsoiling; T2 = maize + dolichos + no subsoiling; T3 = maize alone + no subsoiling; T4 = maize alone with subsoiling. Results from the field experiments showed that rainfall amount and its distribution affected the growth and yield of dolichos and maize. There were significant differences in ground cover between the treatments at $P \leq 0.05$ in all the different weeks after planting when measurements were taken. The penetration resistance in all the plots ranged from 3.83 - 4.18 kg cm⁻² with treatment T4 having the highest and treatment T1 lowest penetration resistance. There were also significant changes in soil N in plots which were under dolichos compared to plots without dolichos. The results obtained in this study also indicated that subsoiling in combination with dolichos had the greatest potential of improving soil properties and crop yields in semi arid environments of Kenya.

Key words: tillage, legume cover crops, crop yield, soil properties

RESUMEN

La baja productividad de los cultivos en las regiones semi áridas de Kenia ha sido atribuido a la baja fertilidad del suelo, bajos insumos, limitaciones de labor y prácticas inapropiadas de preparación del suelo que conducen a la pulverización del suelo. El objetivo de este trabajo fue evaluar el efecto de las leguminosas de cobertura (LCC) sobre las propiedades del suelo y el crecimiento del maíz en la región semi árida de Machakos, Kenia. El trabajo se realizó en campos de cultivo de productores y consistió de cuatro tratamientos, cada uno replicada cuatro veces durante las estaciones de lluvias larga (LR) y corta (SR) de 2008/2009. Los tratamientos fueron T1= maíz + dolichos (*Lablab purpureus*) + subsolado; T2 = maíz + dolichos + no subsolado; T3 = maíz sólo + no subsolado; T4 = maíz sólo + subsolado. Los resultados mostraron que la cantidad de lluvia y su distribución afectaron el crecimiento y producción del dolichos y maíz. Se encontró diferencias en cobertura del suelo ($P < 0.05$) en todas las semanas posteriores a la siembra. La resistencia a la penetración en las parcelas fue de 3.83 a 4.18 kg cm² siendo T4 el mayor y T1 el menor. Se encontró cambios significativos en el contenido de N del suelo en parcelas con dolichos. Los resultados indican que el subsolado combinado con dolichos tienen el mayor potencial para mejorar la propiedades del suelo y producción de los cultivos en las regiones semi áridas de Kenia.

Palabras clave: Preparación de suelo; leguminosas de cobertura; producción de cultivos; propiedades del suelo.

INTRODUCTION

Kenya's economy is heavily dependent on the agricultural sector, which accounts for 25% of the national Gross Domestic Product (GDP) directly, and an additional 27% through linkages with manufacturing, distribution and other service related sectors (Wamuongo and Kiome, 2005). It is the main source of employment and income for up to 80% of the rural population. Smallholder farms average 2 ha in size and are usually cultivated continuously without adequate replenishment of soil nutrients (Mureithi *et al.*, 2004; Okalebo *et al.*, 2006). Diminishing soil fertility, labour constraints, food insecurity and high poverty levels have necessitated alternative interventions such as incorporating legume cover crops into the cropping systems (Gachene and Makau, 2000).

Legumes are grown as cover crops and serve as short-term fallow species. They have proven to be an effective means of sustaining soil fertility (Cheer *et al.*, 2006). They are cheap and can be used to complement animal manures. Legume cover crops (LCC) when incorporated into the soil, improve soil organic matter and moisture retention, soil workability, retard erosion and suppress weeds (Khisa *et al.*, 2002). In addition, grain legumes are important as human food source and are rich in protein, while herbaceous and tree legumes are important livestock feeds.

Screening trials conducted by the Legume Research Network Project (LRNP) in the semi arid areas of Machakos District identified best bet species for the area to be, among others, *Lablab purpureus* cv. Rongai (dolichos lablab) (Gachene and Makau, 2000). *Dolichos lablab* was found to be tolerant to moisture stress, able to nodulate under low moisture conditions, produce viable seeds, utilized as food crops/fodder, provide good ground cover necessary for erosion control and regulating surface soil temperatures (LRNP, 2001). Today there is urgent need to develop methods of maintaining soil fertility and improving soil moisture conservation, where low inputs and appropriate tools are used and which are acceptable to farmers.

The objective of this study was to determine the effect of dolichos lablab (*Lablab purpureus* cv Rongai) when used as a cover crop, and subsoiling on soil properties and maize (*Zea mays* L.) growth in semi arid areas of Machakos District, Kenya.

MATERIALS AND METHODS

Study area

Machakos District lies in the semi arid areas of Eastern Kenya. The district is mainly under agro-climatic zones IV and V which are classified as semi-arid to arid lands respectively (Jaetzold and Schmidt, 2006). It lies between latitudes 0°45' and 1° 31' south and longitudes 36° 45' and 37° 45' east. The rainfall is bi-modal with long rains (LR), occurring from end of March to April/May (about 400 mm) and short rains (SR) from end of October to December (500 mm). The four farms under study were located in Katuaa, Kola, Kitonyiini and Kalama sub-locations of Kalama Division of Machakos District (Fig 1).

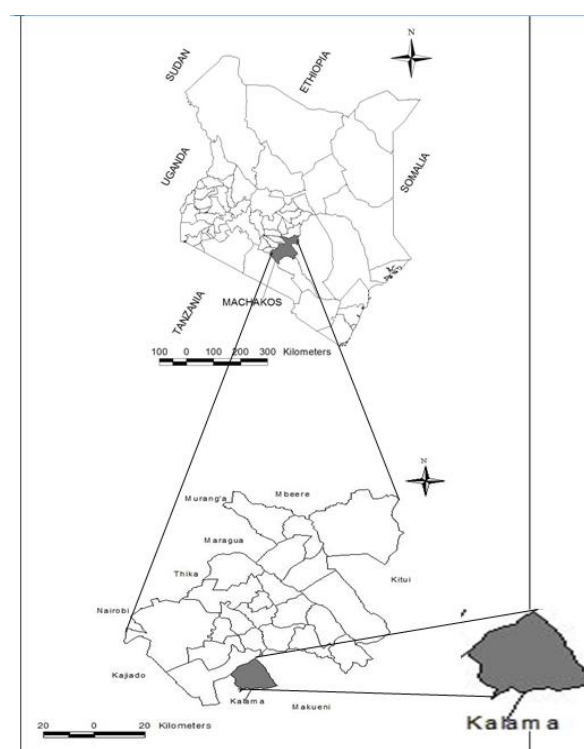


Figure1. Map of Machakos District showing the study area (Kalama Division)

Field experiment

The experiments were carried out in a randomized complete block design in four farms. The four farms acted as the blocks. Selected farms were those belonging to farmers who showed strong interest to host the experimental trials. Trials were carried out in both the long and short rain seasons of 2008/2009. The first trial (long rains) had three treatments (T_1 =maize + dolichos + subsoiling, T_2 = maize + dolichos + no subsoiling, T_3 =maize alone + no

subsoiling). The second trial (short rains) had four treatments (T_1 = maize + dolichos + subsoiling; T_2 = maize + dolichos + no subsoiling; T_3 = maize alone + no subsoiling; T_4 = maize with subsoiling).

A brief description for each of the treatment is given below:

Maize + dolichos + subsoiling (T_1) - This is a conservation agriculture practice where the plot is subsoiled and the maize and dolichos planted as intercrops. This method was introduced by the African Conservation Tillage (ACT), Kenya Network for Draught Animal Technology (KENDAT) and Kenya Conservation Tillage (KCTI). The study was carried out to check the effect of the dolichos and subsoiling on soil properties and maize growth and yield. *Maize + dolichos with no subsoiling (T_2)*. This involved the test crop (maize) which was intercropped with dolichos in a non-subsoiled plot. This was to check the effect of dolichos on soil properties under non-subsoiled conditions. *Maize alone with no subsoiling (T_3)*. This is maize planted in a plot with no subsoiling and was used as the control. Most farmers in the area practice this technology. *Maize with subsoiling (T_4)*. This was done to check the effect of subsoiling on maize growth and yield in the absence of dolichos lablab.

For each treatment, the plot size was a bench terrace of 12x13 m. The subsoiler was used before planting to break the hardpan in order to improve rainwater intake while the ripper was used to widen the furrows. Maize was planted at a spacing of 30 × 75 cm while the dolichos was planted at a spacing of 30 cm within the maize rows. Each of the treatment was replicated four times.

Data collection

Plant growth analysis

Planting of the maize and dolichos was done before the onset of rains. Days to emergence were considered when 75% of the seedlings in the plot had germinated. Four by four meter sub-plots were selected at the centre of each field plot after crop emergence for monitoring purposes. Maize height was monitored monthly using a tape measure.

Other maize data collected included; days to 50% tasseling, silking and stover yield. Other phenological features such as rolling and wilting of leaves were noted, indicative of water stress. Maize stover was cut above ground level, weighed and samples taken for oven drying at 105°C for at least 48 hrs to constant weight, for final stover yield determination.

The legume data collected included seed emergence, flowering, percentage ground cover, pod set and above ground biomass. Ground cover assessment was carried out using the string and dot method (Laflen *et al.*, 1981; Sarrantonina, 1991).

Soil properties

Sampling in the field was done using the gravimetric method (Okalebo *et al.*, 2002). Replicate soil samples were collected in April 2008 for the first season and the second sampling was done in November, 2008 in the second season crop at a depth of 30 cm.

The particle size distribution was done according to Okalebo *et al.*; (2002). Crust strength was measured using a hand cone penetrometer Type 1B, from Eijkelkamp equipment. The below formula was used to calculate the penetration resistance:

$CR = I \times C_s / AC$ Where CR - Cone resistance ($N\ cm^{-2}$); I- Impression on the scale (cm); C_s .spring constant ($N\ cm^{-1}$); AC - Area of cone (cm^2)

Chemical soil properties

Determination of soil pH, organic carbon and total nitrogen were done according to Black (1965). The method described by Mechlich *et al.*, (1962) was used to determine available phosphorous.

Statistical analysis

The data was subjected to ANOVA analysis. The probabilities for the significance of the F-values were determined. Mean separation was done using Least Significant Differences (Steel and Torrie, 1980; Peterson, 1994) at 5% significant level.

RESULTS AND DISCUSSION

Rainfall amount

The rainfall was reliable at the start of the growing season but later ceased and dry conditions set in towards the middle of the two growing seasons of 2008/09. The rainfall was also poorly distributed during the seasons and this led to poor performance of maize and dolichos. Rainfall disappeared during the grain filling stage of maize (LR, 2008) and at ear initiation and grain filling stage in SR, 2008. Flowering and pod set of dolichos was also affected in both seasons. Table 1 shows rainfall distribution of the nearest centre, KARI-Katumani, which is situated in a similar agro-climatic zone (VI). The annual amount of rainfall received in 2008 was 519.40 mm and the average maximum and minimum temperatures were 25.9 and 13.5°C respectively.

Soil characterization

The physical and chemical properties of soil sampled from the experimental sites at the start of the study are presented in Table 2. The pH indicated that the soils were moderately acid. The soils had low organic carbon content of < 2% with an average of 1.40 %. The low organic carbon in cultivated soils may be attributed to low returns of crop residues in the field (Conant *et al.*, 2001). The total N in was < 0.20 % with an average of 0.13 % in all the treatments. The decline in total N under these soils could be due to the lower organic matter input and possibly higher mineralization rates under cultivated conditions (Brady and Weil, 2002). The available P in the soils was moderate ranging from 20 - 25 ppm. Continuously cropped lands have shown to have low levels of P compared to uncultivated soils (Xuewen *et al.*, 1999).

Effect on soil physical and chemical properties

The amount of soil moisture content and its temporal variation as measured in each treatment are presented in Table 3. Season one (LR, 2008) data include the 7, 12 and 17 weeks after planting (WAP) while for season two (SR, 2008) soil moisture content was taken on 6, 14 and 17 WAPs. There were no significant responses at $P \leq 0.05$ in all the weeks after planting (WAPs) except on 17 WAP, when maize stover was harvested in SR, 2008. Soil moisture content decreased over time in the growing season except when there was rainfall. The changes in profile water content

could thus be attributed to a combination of rainfall, soil evaporation, transpiration or crop water uptake (Wanderi *et al.*, 2008). Fig 2 and 3 shows some differences that occurred among the treatments in both seasons at 0 - 15 and 15 - 30 cm depths. At 0-15 cm depth, soil moisture content was on average 8.86, 10.03 and 7.53 % for T₁, T₂, T₃ in LR, 08 and 13.69, 13.57, 19.10 and 13.25 % for T₁, T₂, T₃, T₄ in SR, 08. At 15-30 cm depth, the average soil moisture content was 14.01, 11.82, 11.99 % for T₁, T₂, T₃ respectively for LR, 08 and 14.46, 14.45, 16.64 and 14.58 % respectively for T₁, T₂, T₃, T₄ in SR, 08. This shows that there was more moisture in the soil in SR, 08, than in LR, 08.

The penetration resistance in all the plots ranged from 3.83 – 4.18 kg cm⁻² with T₄ having the highest and lowest in T₁. According to Gicheru (2002), penetration resistance was generally highest in zero tillage at both planting and harvesting and there was no significant effect of mulch on water retention. Soil cover reduces soil crusting and subsequent surface water runoff during rainy periods. This was in agreement with the differences observed whereby T₁ and T₂ had lower resistance than T₃ and T₄ due to the presence of dolichos. The litter fall from dolichos forms part of soil organic matter that help reduce the bulk density, improve the structure, and hence reduce the resistance (Reicosky, 2008).

Table 1: Rainfall data for 2008/09 for Katumani Research Centre, Kenya

Month	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Rainfall (mm)	129	4.5	0.3	1.3	0.2	9.1	23.9	111.6	41.5	74.2	20.3	3.6

Table 2: Initial soil physical and chemical properties at 0-15 cm (average of 4 farms)

Treatment	pH (H ₂ O)	pH (0.01M CaCl ₂)	% OC	% N	P ppm	% Sand	% Silt	% Clay
T ₁	6.3	5.7	1.28	0.14	24.7	47	14	39
	6.5	5.7	1.43	0.12	20.2	44	17	39
T ₃	6.6	5.9	1.49	0.12	20.1	47	17	36
Ave	6.46	5.7	1.40	0.13	21.7	46	16	38

*(T₁=maize + dolichos + subsoiling, T₂= maize + dolichos + no subsoiling, T₃=maize alone + no subsoiling), OC-organic carbon; N-Nitrogen; P- phosphorous; ppm-parts per million

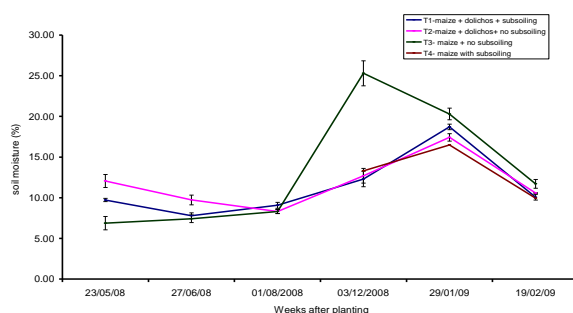


Figure 2: Soil moisture content (%) among the different treatments at 0 -15 cm.

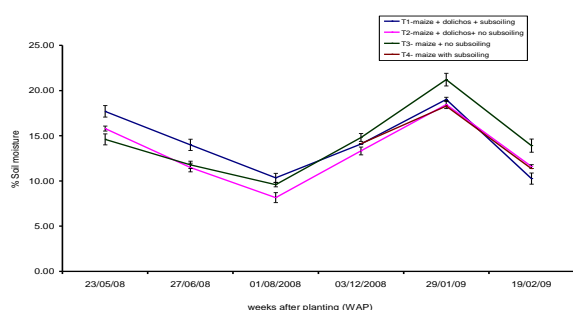


Figure 3: Soil moisture content (%) among the different treatments at 15-30 cm.

In terms of bulk density, the soils ranged from 1.32 - 1.42 g cm⁻³ at the start of SR, 08 and 1.11 - 1.20 g cm⁻³ at the end of the same season. There were some significant differences ($P \leq 0.05$) at 15-30 cm depth at the end of SR, 08. The soil and crop management also influenced the soil bulk densities. Plots with dolichos (T_1 and T_2) had lower bulk densities than in the other plots. Through litter fall, dolichos has been reported to improve soil structure, soil bulk density and soil moisture retention (Steiner, 2002). Subsoiled plots (T_1 and T_4) also showed lower bulk densities than the non subsoiled plots at 0-15 cm depth at the end of SR, 08.

The total nitrogen (TN) in all the soils was $> 0.25\%$ in SR, 08 signifying high levels of N in the field after the treatments. This could be attributed to the dolichos planted in the field. Some variation of total N among the treatments was also observed at both soil depths. There was a decline in TN in T_4 at both soil depths and this could be attributed to the lower organic matter input inform of litter fall. Such conditions are likely to influence the N content of the soil (Conant *et al.*, 2001). A comparison of the N and organic carbon before and after the treatments in both seasons is shown in Table 4. There was some increase in N ($>100\%$) in SR, 08 from the previous season. This could be attributed to the presence of the dolichos planted in the field. Dolichos can fix about 20 kg N/ha under drought

conditions similar to the ones prevailing in the study area (Rochester *et al.*, 1998). This therefore may explain the increase of N in the plots.

Table 3: Comparison of the effects of treatments on soil N and organic carbon in the two seasons (average of four farms)

	% Organic Carbon		% Nitrogen	
	LR, 2008	SR, 2008	LR, 2008	SR, 2008
T_1	1.28	1.33	0.14	0.36
T_2	1.43	1.41	0.12	0.42
T_3	1.49	1.39	0.12	0.43
T_4	-	1.46	-	0.31
Mean	1.4	1.4	0.13	0.38

*(T_1 =maize + dolichos + subsoiling, T_2 = maize + dolichos + no subsoiling, T_3 =maize alone + no subsoiling, T_4 =maize + subsoiling). In LR, 2008 only 3 treatments were applied.

Effect on crop growth and yield

Dolichos germination was good (80 %) and emergence occurred within 5-7 days after planting in both seasons and for all the treatments. Onset of flowering was at 14 - 17 weeks after planting (WAP), 50% flowering at 18 WAP and 50% pod set at 20 WAP in SR, 08. Phenological data for dolichos for LR, 08 season was not recorded due to its inconsistency. After germination, the seedling vigor for dolichos could be rated as good - excellent in all seasons. There was however a reversal in vigor for both crops at 8 WAP in SR, 08 due to the poor rainfall amount and distribution.

Both maize and dolichos cover measurements were taken at 4, 8 and 12 WAP. Early in the season, the dolichos plots (T_1 and T_2) had a higher ground cover than maize with a peak at 8 WAP (48.2 %) and thereafter tended to decrease slowly due to moisture stress. This could be attributed to the higher plant population in the intercrop plots than in the sole cropped plots. There were significant differences among the treatments at $P \leq 0.05$ in all the different weeks after planting (WAP). T_1 and T_2 gave higher measurements, 34 and 31% at 4 WAP and 48 and 47 % at 8 WAP respectively. Treatment T_1 and T_2 were significantly different at 4 WAP. On average T_1 gave higher measurements of ground cover (38 %) and this could be attributed to the subsoiling that allowed greater infiltration of rainwater thus a greater canopy was achieved.

The dolichos biomass was taken when the maize was harvested at 17 WAP using a 0.5 m by 0.5 m quadrant.

Although there were no significant differences among the treatments at $P \leq 0.05$, however T_1 had greater biomass than T_2 with 6.63 and 5.17 t DM ha⁻¹ respectively. This could be attributed to the greater canopy created by the dolichos due to greater infiltration of water aided by subsoiling and the less evaporation losses experienced in the plots due to the higher ground cover. Dolichos lablab can produce 3.8 t DM ha⁻¹ at 10 weeks after planting (WAP) compared to *Crotalaria ochroleuca* and *Mucuna pruriens* with 2.2 and 2.8 t DM ha⁻¹ respectively (LRNP, 2002). It was further observed that plots with legume cover (T_1 and T_2) had less weed composition compared with T_3 and T_4 . Through visual assessment among the treatments in the different farms, it was observed that the dolichos suppressed weeds. This has been mentioned as one of the advantages of using cover crops in Conservation Agriculture (FAO, 2008).

Phenological data for maize was as follows: In LR, 2008, 9th leaf stage was achieved at 5 WAP, tasseling at 6 WAP, silking at 7 WAP and harvesting of the stover was done at 20 WAP. In SR, 2008, 9th leaf stage was at 4 - 5 WAP, tasseling at 8 WAP, silking at 9 WAP and harvesting at 17 WAP. Ear initiation and grain filling for maize was greatly affected and thus no data was recorded for maize grain yields. Occurrence of drought at the grain filling stage of maize reduces the photosynthetic rate and impairs assimilate translocation in kernels leading to reduced maize grain yield (Gitari, 2008). Subsoiled plots (T_1 and T_4) had taller plants (2-10 cm) more than in the non-subsoiled plots as the WAPs progressed. The height difference was attributed probably to more water infiltrating into the soil in the subsoiled plots (T_1 and T_4) compared to the non-subsoiled plots (T_2 and T_3). Plots with dolichos (T_1 and T_2) gave higher stover yield than in the maize alone plots (T_3) in LR, 2008. This could probably be attributed to the dolichos cover that helped in regulating the soil temperature and thus reduced evaporation water losses (Gachene *et al.*, 2004). In SR, 2008, stover yields were higher in T_3 and T_4 than in T_1 and T_2 . This gives a contrasting observation to the previous observation (LR, 08). This could also be due to lack of competition of nutrients, water and light with the legume cover crop (Wanderi *et al.*, 2003). The moisture levels of T_3 and T_4 were however higher than T_1 and T_2 and thus resulting in better yields. In SR, 2008, the maize stover yields were significantly different at $P \leq 0.05$ among the treatments.

CONCLUSION

Results from this study showed that rainfall amount and its distribution affected the growth of dolichos and maize. The rainfall influenced the soil moisture content throughout the study period. Soil moisture

content generally decreased over time in the growing season. The changes in profile water content could probably be attributed to a combination of rainfall, soil evaporation, transpiration or crop water uptake. The greatest differences in moisture content occurred when the soil moisture contents were higher after the rains. Legume cover increased the maize stover yields and therefore intercropping maize with dolichos does not adversely affect the performance of the crop. There were also some changes in the soil physical and chemical properties namely the soil moisture content, organic carbon, total nitrogen, penetration resistance and the bulk density. Subsoiling increased water infiltration, legume biomass and showed some differences in maize performance.

ACKNOWLEDGEMENTS

The authors acknowledge AIDA (Agricultural Innovation in Dry land Africa) project for funding the research and to the University of Nairobi for the technical support during implementation.

REFERENCES

- Black, C.A. (Ed) 1965. Methods of soil analysis part 2. *American Society of Agronomy*. Madison, Wisconsin, U.S.A.
- Brady, N.C and Weil, R. R. 2002. The Nature and Properties of soils. Pearson Education, Inc.
- Cheer, C. M., Scholberg, J.M.S. and McSorley, R. 2006. Green manure approaches to crop production: A synthesis. *Agronomy Journal*. **98**: 302-319.
- Conant, R.T., Paustian, K and Elliot, E.T. 2001. Grassland management and conversion into grassland. Effects of soil carbon. *Ecological Application*. **11**:343-355.
- Food and Agriculture Organization (FAO). 2008. Investing in sustainable agricultural intensification: The role of Conservation Agriculture.
- Gachene, C.K., Karanja, N., Mureithi, J., Khisa, P. and Maina, J. 2004. Farmers' evaluation of legume cover crops for erosion control in Gathwariga catchment, Kenya. *International Journal of Agriculture and Rural Development*. **5**: 176-186.
- Gachene, C.K.K and Makau, M., 2000. Screening legumes cover crops for dry season survival in a semi arid environment of Kenya In: Proceedings of the First Scientific Conference of the Soil Management Project (SMP) and the Legume Research Network Project (LRNP), Kanamai, Mombasa, Kenya. 24-26 March 1997. KARI, Soil

- Management and Legume Research Network Projects, Kenya. Pp 77-86.
- Gicheru, P. T. 2002. The effect of different soil management practices on crust formation, soil moisture conservation and crop growth in Machaang'a area, Mbeere district, Kenya. PhD thesis. University of Nairobi.
- Gitari, J. N. 2008. Determination of factors influencing the efficiency of legume green manures for maize production in Embu, Kenya. PhD thesis. Kenyatta University.
- Jaetzold, R. and Schmidt, H. 2006. Farm Management handbook of Kenya. Vol II/C1. Natural conditions and farmer management information-Part C, East Kenya.
- Khisa, P., Gachene, C.K., Karanja, N. K. and Mureithi, J.G. 2002. The effect of post harvest cover crop on soil erosion in a maize-legume based cropping system in Gatanga, Kenya. *Journal of Agriculture in the Tropics and subtropics*. **103**: 17-28.
- Laflen, J. M., Amemiya, M. and Hintz, E.A. 1981. Measuring crop residue cover. *Journal of Soil and Water Conservation*. **36**:341-343.
- LRNP, 2001. Legume Research Network Project Newsletter, Issue No.5. Kenya Agricultural Research Institute
- LRNP, 2002. Legume Research Network Project Newsletter, Issue No.7. Kenya Agricultural Research Institute.
- Mechlich, A.A., Pinkerton, Robertson, W and Kempton, R. 1962. Mass analysis methods for soil fertility evaluation. Internal publication, Ministry of Agriculture, Nairobi.
- Mureithi, J. G., Gachene, C.K.K. and Wamungo, J. 2004. Legume cover crops research in Kenya: Experience of the Legume Research Network Project KARI Technical note. Series No.12.
- Okalebo, J. R., Gathua K.W. and Woomer P.L. 2002. Laboratory methods of soil and plant analysis: A working Manual. 2nd Edn. TSBF-CIAT and Sacred Africa, Nairobi, Kenya
- Okalebo, J.R., Othieno, C.O., Woomer, P.L., Karanja, N.K., Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N., Mueasya, R.M., Bationo, A and Mukhwana, E.J. 2006. Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems*. **76**: 153-170.
- Peterson, R. G. 1994. Agricultural Field Experiments-Design and Analysis. Mercel. Dekker, Inc. New York.
- Reicosky, D.C. 2008. Carbon sequestration and environmental benefits from no-till systems. In: *No-Till Farming systems*. Special Publication No.3, World Association of Soil and Water Conservation, Bangkok. ISBN: 978-974-8391-60-1. Pp 43-58.
- Rochester, I.J., Peoples, M.B., Constable, G.A and Gault, R.R. 1998. Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. *Australian Journal of Experimental Agriculture* **38**(3):253-260
- Sarrantonio, M. 1991. Methodologies for screening soil improving legumes. Rodale Institute Research Center, USA. pp 310.
- Steel, R. G. D. and Torrie, J. H. 1980. Principles and procedures of Statistics. A Biometrical approach Second Ed. McGraw-Hill: Auckland, Lisbon, London .Mexico. International Edition.
- Steiner, K. 2002. Impact of Conservation tillage on Soil Quality. African Conservation Tillage Network Information series No.4. Harare: ACT.
- Wamungo, J.W and Kiome, R. M. 2005. The role of Kenya Agricultural research institute in meeting challenges of food security. In: Capacity building for Land Resource Management to meet the challenges of food security in Africa. SSSEA Proceedings of the 21st annual conference 1-5th Dec 2003, Eldoret, Kenya. (Eds)
- Wanderi, S.W., Mburu M.W.K. and Silim S.N. 2008. Light and water use in maize (*Zea mays*)-pigeon pea (*Cajanus cajan*) intercrop under semi-arid conditions of Kenya. In: Proceedings of the 10th KARI Biennial scientific conference, 12- 17th November, 2006. Nairobi.
- Xuwen, H., Skidmore, E. L and Tibke, G. 1999. Effects of grazing and cultivation on forest plant communities in Mount Elgon National park, Uganda. 10th International Soil Conservation Organization, Purdue University.

Submitted February 26, 2010 – Accepted August 17, 2010
Revised received October 13, 2010